GENESIS AND MORPHOLOGICAL PECULIARITIES OF CAVE ICE DEPOSITS OF LAKE BAIKAL

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Abstract: Ice cave observations stretch from 1976 to the present in Baikal region. According to the origin of the coldness and accumulation of snow and ice the underground cavities can be divided into 3 main groups: 1. Cold caves (11 cavities) with a sack-shaped morphology are characterized by the descending winter type of air circulation. Formation of ice is due to the freezing of water which comes into cavity through the fissures, as well as forming from the air through the process of sublimation. In genesis they are congelation and sublimated ice. Snow-banks made as a result of accumulation of snow in underground cavities after snow-storms, as well as the falls of ice sublimated crystals are responsible for formation of snow-infiltrated ice, usually near the entrances. 2. Thermoventilated cave (2), having few entrances, which are distinguished by the change of direction of air draught in the cold and warm seasons. Congelation and sublimated ice have been observed here and also snow-infiltrated ice. 3. Karstic pit, ice is formed as a result of recrystallization of the snow supplied to the cave through the entrance in cold period of the year (snow-infiltrated ice). Sublimated ice is fixed near the entrance.

In caves researched the following morphological types of cave ice deposits are occurred: congelation ice – droplet-accumulative aufeises, aufeis-layers, mantle of ice, ice of the lake, segregated and vein ice; sublimated ice – hexahedral plates and needle forms and snow-infiltrated ice – snow-banks.

Taking into consideration the genesis of cave ice and the morphological peculiarities of cave ice deposits the system of topographical signs for the presentation of the cave glaciation on the underground maps is proposed.

Key words: cave ice, morphology, genesis, Baikal, degradation

GEOGRAPHICAL POSITION OF REGION RESEARCHED

Lake Baikal is the pearl and the heart of Asia. The region explored is situated in the central part of the western shore of Lake Baikal, geographical position is N 52°20' – 53°30' and E 105°40' – 107°50', the altitudes vary from 450 to 1500 – 1700 m a.s.l. (Fig. 1).

The region considered is confined by the Primorsky Range on the West and by the Lake Baikal on the East. Two main building blocks are distinguished in relief. Northern part (caves 1 – 10, see Fig.1), presented by a typical hummocky topography: gently smoothed out forms of local watersheds (at 350 – 380 m above the level of Lake Baikal) divided by dry trough-shaped valleys which have low concave sides and flat bottoms with a width of 300-600 m. Southern part (caves 11 – 14, see Fig. 1), there are the low folded block-mountains with the dominant heights of 1000 m which are characterized by the plane summits and V-shaped valleys with a width of 200 – 600 m. By geostructural signs the area belongs to the Sayano-Baikal fold belt. Metamorphic complexes from Archaean-Lower Proterozoic consisting of gneisses, amphibolites, schists, marbles and calciphyres are folded in structures of NE direction. Karstic rocks represented predominantly by marbles have a thickness of strata from 1 to 200 – 250 m.

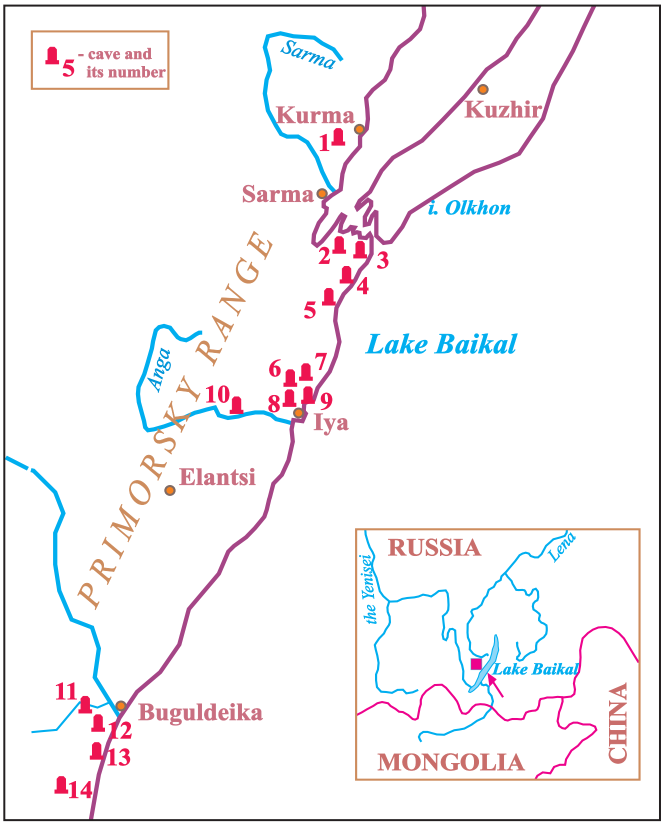

Fig. 1. Region explored. Names of the caves : 1 – Nuganskaya, 2 – Bolshaya Baidinskaya, 3 – Malaya Baidinsakaya, 4 – Mechta, 5 – Skotomogilnik, 6 – Iya, 7 – Ryadovaya, 8 – Vologodskogo, 9 – Oktyabrskaya, 10 – Sluchainaya, 11 – Zagadai, 12 – Burun, 13 – Ice Burun, 14 – Korona

Climatic peculiarities are defined by two main factors: huge water volume of Lake Baikal and the Primorsky Range blocking the moisture which is brought by winds predominantly of the western and north-western directions. Average annual temperature of the air varies from -0.4 °C in the northern part to -2.3 °C in the southern one, average annual precipitation accordingly – from 182 to 450 mm, less than 10 % falls in cold part of the year.

14 caves with snow and ice deposits are observed here (Fig. 1). Its morphometric characters and volumes of its ice accumulations are represented in Table 1.

Table 1. Ice caves of Lake Baikal.

N	Name of the cave	Length	Depth	Volume [m^3]	
		[m]		cave	ice
1	Nuganskaya	5	2	-	-
2	Bolshaya Baidinskaya	45	11	600	120
3	Malaya Baidinskaya	55	8	180	8
4	Mechta	823	52	8500	70
5	Skotomogilnik	30	8	-	-
6	Iya	578	32	1200	3
7	Ryadovaya	450	57	2500	3
8	Vologodskogo	46	17	350	12
9	Oktyabrskaya	80	20	290	2
10	Sluchainaya	35	12	250	2
11	Zagadai	600	20	5000	2.5
12	Burun	26	3	200	4.5
13	Ice Burun	67	44/46	1150	4
14	Korona	76	12	-	-

GENETIC AND MORPHOLOGICAL PECULIARITIES OF CAVE ICE FORMATIONS

Ice cave observations in Baikal region are accomplished since 1976. The caves considered are characterized by wide spread of snow and ice formations. Seasonal ice is formed in places where the summer temperatures of the air rise above 0 °C. It is either near cave entrances or inside underground systems under fissures or under roofs situated near the surface. Perennial ice formations are developed in places where average annual temperatures are negative and summer ones are near to 0 °C. Underground cavities can be divided into 3 types, according to the origin of the coldness and accumulation of snow and ice in the caves.

Cold caves with a sack-shaped morphology, Nuganskaya, Bolshaya and Malaya Baidinskaya, Mechta, Skotomogilnik, Ryadovaya, Oktyabrskaya, Zagadai, Ice Burun and Korona are grouped in the *first type*. These caves are characterized by descending winter type of air circulation. Formation of ice is due to the freezing of water, which comes into cavity through fissures, as well as forming from the air through the process of sublimation. In origin they are congelation and sublimated ice. Snow-banks made as a result of accumulation of snow in underground cavities after snow-storms, as well as the falls of ice sublimated crystals are responsible for formation of deposited and metamorphosed ice near entrances, and in Bolshaya Baidinskaya also between upper and lower halls. In its turn the snow-banks play an important role in supporting coldness in cavities.

Ice stalactites, stalagmites and stalagnates formed as a result of supply of water-droplets in zone of negative temperatures are wide-spread in caves of the type considered. Seasonal ice stalactites and stalagmites have been noted every year near the entrances in caves Bolshaya Baidinskaya (Fig. 2A), Malaya Baidinskaya, Mechta, Skotomogilnik, Iya, Ryadovaya, Ice Burun and Korona as well as in big halls inside both Baidinskaya and the Throne hall in Mechta. Forms and sizes of ice droplets are distinguished by considerable variety. Conic, complicated, keel stalactites and complicated stalagmites occur (description of the forms of stalactites and stalagmites is given in line with [3]). According to data of long-term observations the biggest stalactite was registered in May 1996 with the length of 1.0 m, diameter near the foundation of 55 cm – in Khoroshikh hall in Bolshaya Baidinskaya. Usually the sizes of seasonal ice stalactites in caves considered are not more than 0.5 m, and stalagmites not more than 0.3 – 0.4 m, but in Malaya Baidinskaya and Ryadovaya correspondingly 0.25 – 0.30 and 0.03 – 0.10 m. Only stalagmites with the height of 0.5 m are marked in Zagadai. In Ryadovaya, Ice Burun and Korona the ice droplets thaw by July, in another cavities – by August.

The intensity of the thaw reaches 0.38 – 0.40 cm/day. Perennial ice stalactites, stalagmites and stalagnates have been recorded in Mechta and Bolshaya Baidinskaya. The following ice formations have been revealed: conic, complicated, keel stalactites, stalagmites-drum sticks, complicated, large ice-mass under stalactites. The following stalagnates (column) have also been observed: conic from below, swollen in the middle part, with a large ice foundation and stalagmites. Ice stalactites reach a height of 1 – 1.5 m, stalagmites – 2 – 2.5 m. Of special note are the huge stalagnates in Mechta, with a height of more than 3 m and diameter near the foundation of up to 1 m. The position of seasonal and perennial droplets indicates the direction of fissures along which the underground waters penetrate into cavity.

Aufeis-layers forming under supply of liquid water in parts of cavities, frozen below 0 °C, are wide-spread on the horizontal and subhorizontal areas in both Baidinskaya, Mechta, Skotomogilnik, Ryadovaya, Oktyabrskaya, Ice Burun and Korona. Areas of these aufeises not exceeding 8 – 10 m^2, they thaw completely by July. Perennial aufeis-layers are developed in Mechta, Bolshaya and Malaya Baidinskaya. The area of aufeis body in Mechta reaches to 200 m^2, in Bolshaya Baidinskaya to 50 m^2, in Malaya Baidinskaya to 20 m^2, ice depth varies from

0.1 to 0.4 m in all caves. Aufeis in Mechta is characterized by hydro-carbonate-calcium composition with mineralization 118 mg/l.

In cold period of the year in Bolshaya Baidinskaya, Malaya Baidinskaya, Mechta and Ryadovaya condensed--congelation ice (mantle of ice) has developed. Inverted distribution of air temperatures in underground systems conditions the formation of this ice. For example, the vertical gradient in Bolshaya Baidinskaya in the winter season is 0.8 – 1.4 °C per 1 m. Condensed moisture forming in upper parts of the walls and on the roofs of underground cavities flows down and freezes in the zone of negative temperatures. The mantle of icing with depth 5 – 15 cm, as well as ice conic stalactites with a length of 15 – 20 cm and diameter near the foundation of up to 5 cm are formed in the lower parts of passages in caves considered.

Small lakes of 15 – 20 cm depth are situated in Bolshaya and Malaya Baidinskaya and Mechta, the sizes of the lakes are 4.5 × 2.2, 2 × 1.5 and 5 × 1.5 m respectively. They freeze in winter. Seasonal segregation ice forming under slow chilling of ground have been found at the bottom of upper halls in both Baidinskaya.

Seasonal and perennial crystals of underground hoarfrost are widely represented in caves researched. Crystals are formed as a result of the fall of atmospheric moisture on the surfaces with a temperature below 0 °C. Seasonal formations have been noted near entrances in all underground cavities considered, they thaw completely at the beginning of the summer. Perennial crystals have been registered directly near perennial aufeis-layers in both Baidinskaya and Mechta: on the one hand, humidity of the air is supported by sublimation of ice and on the other hand, a zone of negative temperatures is set up near perennial aufeis-layers. The latter defines the minimum thaw of ice crystals. Sizes of crystals change during the year, maximum ones are noted from March to June. Usually the ice crystals have a form of the hexahedral plates, maximum sizes are 3 – 4 cm in diameter. Hoarfrost in the shape of needles with a height of 0.3 – 0.5 cm have been observed in Bolshaya Baidinskaya only. Spring snow-banks with volume of snow-icy accumulation up to 5 – 15 m³ have been noted in all caves. They thaw by June. A perennial snow-bank made by snow, firn and ice is disposed in Bolshaya Baidinskaya, ice depth is 8.2 m, volume is 110 m³. Remains of malacofauna found in lower part of snow-bank date it from Pleistocene-Holocene [4]. Question about origin of this snow-bank is being discussed.

Caves Iya and Burun are the caves of the second type, thermoventilated ones, the cavities open at both ends, which is distinguished by the change of direction of air draught in the cold and warm seasons (Fig. 2 B). Congelation and sublimated ice have been observed here. Seasonal stalactites are noted in central parts of Iya and in Burun, with a length of not more than 12 – 15 cm, diameters near the foundation are 3 – 5 cm. Until to1997 the perennial aufeis-layer was disposed here in Ice hall, the ice had hydro-carbonate-calcium composition, mineralization was 189 mg/l. Mantle of ice and vein ice is marked in Burun. Seasonal hoarfrost has been registered near entrances of the cavities, it is the hexahedrons with sizes 1 – 3 cm in diameter. During the whole year crystals of hoarfrost cover the roofs and walls of the Ice hall in Iya and the underground system adjoining it. In the Ice hall there are ice needles with a height of up to 0.5 cm but in the adjoining system there are ice hexahedrons. The sizes of hexahedral crystals increase in direction from the second (lower) entrance to inside parts of the cave – from 0.5 to 3 – 5 cm in diameter. Seasonal spring snow-banks have been fixed near the entrances of the caves explored.

Vertical cave Vologodskogo represents the third type (Fig. 2 C), a karstic pit with snow and ice, ice is formed as a result of recrystallization of snow supplied to the cave through the entrance (its sizes are 3.5 x 2 m) in cold period of the year. Summer snow-banks with a volume of snow and ice of 10 – 12 m³ (in accordance with the climatic conditions of the year) are developed here and are conserved until August. Seasonal hexahedral ice crystals have been noted near the entrance.

Types of ice in caves of Lake Baikal are represented in Table 2.

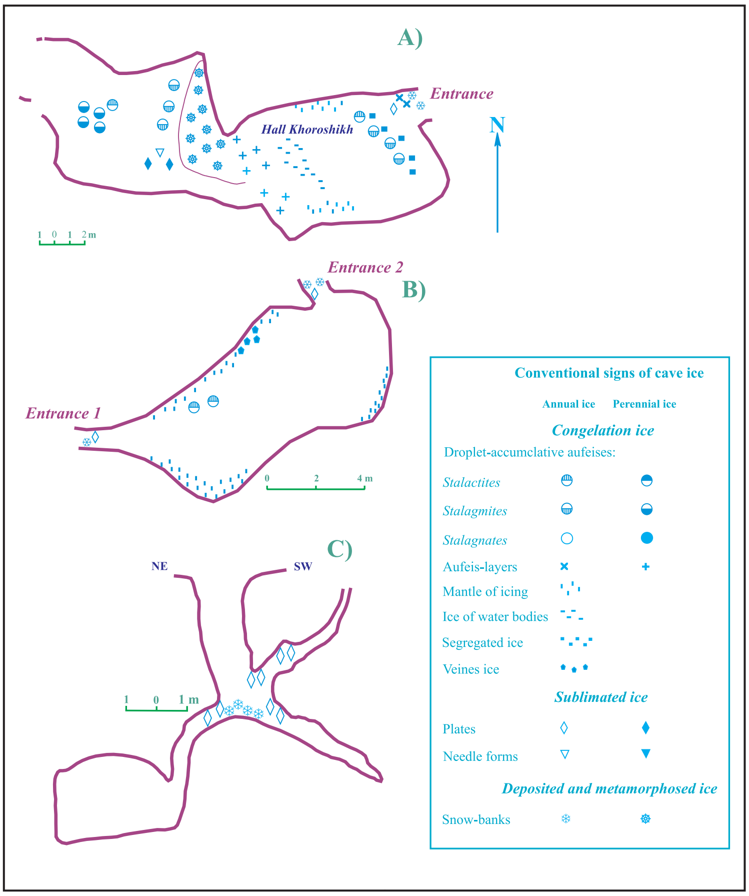

Fig. 2. Ice caves of Lake Baikal: A – Bolshaya Baidinskaya (plan), B – Burun (plan), C – Vologodskogo (vertical cross-section)

Table 2. Baikal cave ice.

Cave	Congelation ice								Sublimated ice				Deposited and metamprphosed ice		
	Droplet-accumulative aufeis		Aufeis-layers		Mantle of ice	Ice of the lake	Segregated ice	Vein ice	Hexahedral shapes		Needle forms		Snowbanks		
	A*	P	A	P					A	P	A	P	Sp	S	P
Nuganskaya					+				+						
Bolshaya Baidinskaya	+	+	+	+	+	+	+		+	+	+		+		+
Malaya Baidinskaya	+		+	+	+	+	+		+	+			+		
Mechta	+	+	+	+	+	+			+	+			+		
Skotomogilnik	+		+						+				+		
Iya	+								+	+		+	+		
Ryadovaya	+		+		+				+				+		
Vologodskogo									+					+	
Oktyabrskaya			+						+				+		
Sluchainaya					+				+				+		
Zagadai	+								+				+		
Burun	+				+			+	+				+		
Burun-ledyanaya	+		+						+				+		
Korona	+		+						+				+		

** A– annual, P – perennial, Sp – spring, S - summer*

DYNAMICS OF CAVE GLACIATION

Observations of the dynamics of cave glaciation in Baikal region stretch from 1976 to the present. It is in this short period that the essential changes in its state were registered. From the seventies of last century the considerable decrease of the sizes of cave glaciation has been observed. So, complete degradation of the aufeis--layer occurred from 1976 to 1997 in Ice hall of cave Iya: in November 1977 the area of one was 226 m^2 with an ice depth from 1.5 to 2.5 – 2.8 m; in July 1993 its size have decreased to 6.9 m^2 with an ice depth from 6 to 88 cm, in July 1996 – to 1.5 m^2 and maximum ice depth 7 – 8 cm (Fig. 3 A). Complete thaw of aufeis-layer was registered in July 1997. Within the span of twenty years, the annual thaw of aufeis-layer averaged 11.3 m^2. The same considerable degradation of aufeis-layer was observed in Bolshaya Baidinskaya (Fig. 3 B): in July 1993 the area of ice in Khoroshikh hall was 23.3 m^2, in October 1998 – 14.4 m^2, in June 2003 – 10.5 and in May 2005 – only 7.8 m^2. Within the span of twelve years, the annual thaw of aufeis-layer averaged 1.2 m^2.

Observations of the dynamics of aufeis-layers in both Baidinsakaya and Mechta were marked. In Bolshaya Baidinskaya marks were done on the walls at observations points to the left, at the centre, to the right of the ice body and on the frozen block, in Malaya Baidinskaya – on the frozen block too, but in Mechta – they were on the walls to the left of the ice stalagmites named Organ and Ded

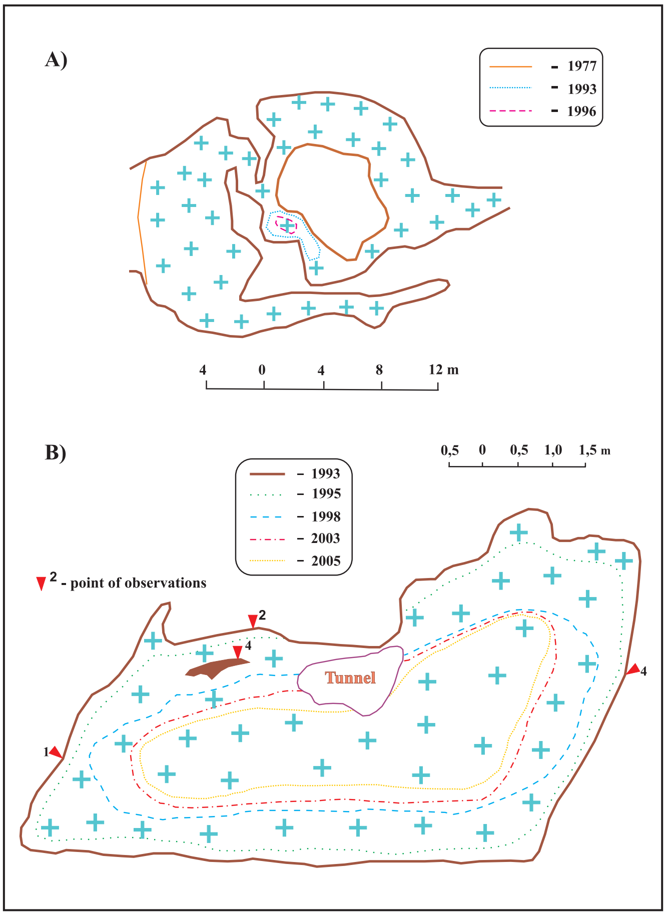

Fig. 3. Degradation of aufeis-layers in caves: A – Iya, B – Bolshaya Baidinskaya

Table 3. Degradation of perennial aufeis-layers in caves Bolshaya Baidinskaya, Malaya Baidinskaya and Mechta, cm (marks from 26th July 1995).

Data of observations	Bolshaya Baidinskaya				Malaya Baidinskaya	Mechta	
	left	at the centre	right	on the block		Organ	Ded Moroz
16th September 1995	4.5	8.5	2.5	3.2	1.3	0.8	
1th May 1996	2.5	10.3	12.0	9.7	1.0		
13th April 1997	10.0	12.0	9.0	collapse	1.0		
26th October 1998	2.5	27.5	16.0		-	3.5	marking
1th May 2005	78.5	59.5	86.0		-	16.5	29.5
Average intensity per year	10.8	11.8	12.6	12.9	1.7	2.1	4.2

Moroz. During every following visit the measuring of the distance, for which the ice limit was moved away by comparison with the previous state, was accomplished. As may be inferred from Table 3 considerable degradation of cave ice is noted in both Baidinskaya and Mechta, starting from 1995. During last ten years the rate of ice retreat varies from 3.2 cm (in Mechta) up to 11.7 cm per year (in Bolshaya Baidinskaya). The rate of the thaw (observations by the frozen blocks in both Baidinskaya) achieves from 1.7 up to 12.9 cm per year. And as for Mechta, in autumn 1976, in system Metro, milky-white ice was characterized by a depth of 0.5 – 0.7 m, in autumn 1998 the dirty-black ice had a depth not more 20 – 21 cm, but in spring 2005 the ice was absent on the whole of the system considered, the temperature of the ground was +0,2 °C. The intensity of the thaw is 3 cm per year. It is evident that the climatic changes cause the considerable degradation of cave glaciation in Priolhonie. In effect, as it is illustrated by Fig. 4, until 1967 the small fluctuations of average annual temperature of the air, conditioned by the cyclicity (25, 11-years, etc.) of nature processes, are revealed.

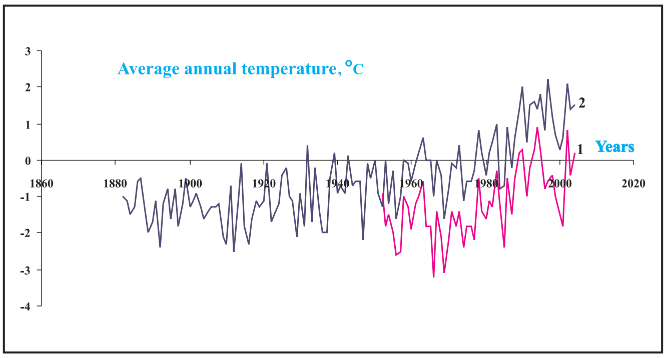

Fig. 4. Dynamics of average annual temperature by the meteorological stations: 1 – Irkutsk- observatory, 2 – Uzur

After 1967 the steady trend in increase of average annual temperature of the air is noted. It has been just this increase which is responsible for the degradation of cave ice in region researched. The following meteorological data were used for analysis: observations at the meteorological station Irkutsk-observatory, characterized by the longest period of observations in Irkutsk amphitheatre – duration from 1830 interruption and from 1882 to 2003 – without interruption, as well as observations at the Uzur station, which is situated 75 km to the NE from Bolshaya Baidinskaya, with the same period of meteorological observations. Both data published [1, 2] and unpublished (starting from 1965 the materials were received by the treatment of average month temperatures by Meteorological monthly books) were used. And its turn, the considerable degradation of cave glaciation is the foundation to consider the cave ice as an indicator of the climatic changes in Baikal region.

CONCLUSIONS

- Three main types of cave ice are observed in 14 karstic caves of Lake Baikal: congelation, sublimated and deposited-metamorphosed.
- According to the origin of the coldness and accumulation of snow and ice three types of cavities are distinguished here: 11 cold sack-shaped caves, 2 thermoventilated cavities characterizing by the change of direction of air draught in the cold and warm season and vertical pit.
- The system of topographical signs for the presentation of cave ice formations on the underground maps is proposed.
- The rate of ice retreat varies from 3.2 up to 11.7 cm per year and the rate of the its thaw achieves from 1.7 up to 12.9 cm per year.

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